J. W. BONGBERG

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STUDIES OF PHYSICAL CHARACTERISTICS OF HIGH AND LOW RISK PONDEROSA PINES, BLACK'S MOUNTAIN EXPERIMENTAL FOREST

SEASON OF 1941

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STUDIES OF PHYSICAL CHARACTERISTICS OF HIGH AND LOW RISK PONDEROSA PINES, BLACK'S MOUNTAIN EXPERIMENTAL FOREST, SEASON OF 1941

APPROVED BY:

J. M. MILLER
Senior Entomologist, In Charge

SUBMITTED BY:

M. D. WYGANT
Assistant Entomologist

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STUDIES OF PHYSICAL CHARACTERISTICS OF HIGH AND LOW RISK PONDEROSA PINES, BLACK'S MOUNTAIN EXPERIMENTAL FOREST, SEASON OF 1941 1/

INTRODUCTION

Four risk classes were set up in 1938 by members of the Berkeley Forest Insect Laboratory for the classification of ponderosa pine in the eastside stands according to their susceptibility to attack by subcortical insects. The classes were set up as representing four degrees of health from risk 1, the most vigorous class, to risk 4, the least vigorous class. The descriptions of the classes were based on the apparent health condition of the needles, twigs, and branches. At that time the need for empirical values for some of the characters was realized. Accordingly needle length and needle complement per twig were measured on 6 trees during the summer of 1938 and reported upon by Bongberg (1939). Hall (1941) continued with a preliminary study in 1940 at Hat Creek by taking measurements on 8 trees. In addition to needle measurements, Hall also measured twig growth. Both studies showed considerable differences in the characters between high and low risk trees. Because of the suggestive nature of these results, and because of the need for a better knowledge of the characteristics of trees of different susceptibilities, a more comprehensive study of this problem was undertaken in 1941. Six physical characters of the trees were chosen for measurement. These were needle length, needle diameter, needle retention, needle complement per twig, twig growth, and ring growth. In addition, it was hoped that the examination and the analysis of growth in different parts of the trees would provide clues to some of the causes of decadence. The problem, then, included both a consideration of the causes of decadence in the pines and measurements of the effects of decadence upon growth and physical characteristics of the trees. Because of the relatively small number of trees that were examined, the results of this season are not final but should be regarded as a step to studies to come. Certain of the results, however, may contribute to a better understanding of the risk classification.

PROCEDURE

Seventeen high risk and 16 low risk trees were felled and analyzed to determine wherein the trees in the two groups differed. For samples of high risk it was originally planned to use newly infested trees on which risk ratings had been made before the trees were killed, it being assumed that attack is the criterion of high risk. Such trees, however, were not always available throughout the summer, and it was found, moreover, that the branches and needles shatter very badly on infested trees unless felled

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1/ The writer is very grateful to Dr. R. C. Hall for aid in outlining the study, for suggestions from time to time as the study progressed, and for help in applying a statistical analysis to the data. The writer is also indebted to J. F. Bongberg and J. W. Johnson for the excellent cooperation in providing assistance and suggestions throughout the season.

soon after attack. Because of these circumstances it was necessary to use 11 green, unattacked trees, classed as risk 4, and cut by the Forest Service at Black's Mountain Experimental Forest to fill out the quota of high risk trees. Vigorous trees appraised as risk 1 and cut by the Forest Service were used for comparison with the risk 4. In addition, limited measurements were made on 17 trees in risk class 2 for risk class comparisons and class descriptions.

Before felling, each tree was photographed by the writer and classified by Dunning, Keen, and risk class and crown characters appraised by J. W. Bongberg and in some cases by J. W. Johnson. The photograph provided a record of appearance, and the appraisal of crown characters provided an estimate of decadence for comparison with actual measurements taken on the felled trees. Appended to the Berkeley file copy are photographs and summaries of the measurements of each tree.

After each tree was felled, height and crown length measurements were taken and the tree examined superficially for presence of insects or injury that might be contributing to decadence. Wedges or discs at stump, mid, and top of bole and samples of 15 twigs were taken for measurement in the laboratory. Of this sample of 15 twigs, 5 were from the upper 1/3 of crown and referred to as top crown, 5 from the middle 1/3 and referred to as mid crown, and 5 from the lower 1/3 of the crown and referred to as the lower crown.

The trees for analysis were selected according to risk class with secondary attention to selection according to Dunning and Keen class. It would have been desirable to have used risk class samples with identical frequency of distribution in the tree classes so as to eliminate as much as possible influence in growth due to tree class.

A brief summary of the types and classification of the trees used for the analysis is given in table 1. The trees in risk class 1 were somewhat higher in vigor according to the Keen tree classification than the risk 4 trees. Most of the trees were in the overmature class. Distribution according to age, D.B.H., and height in each risk class was quite comparable.

RESULTS

Number of Needle Fascicles per Twig

A summary of the number of needle fascicles per twig is shown in table 2 by risk class and by portion of crown. The average needle fascicle complement per twig on the risk 1 trees was much greater than on the risk 4, however, the variation in complement within each risk class was great. For example in risk class 1, the average complement per twig in top crown of tree 1466 was 292.2 and on tree 1667 was 123.8. These trees were Keen Class 4A and 3A respectively. In risk class 4 the variation was from 249.4 to 70.2. On the meagre sample, needle complement appeared to be independent of tree class within each risk class. The difference between the mean complement of risk 1 and risk 4 proved to be highly significant. Between risk 1 and 2 there was no significance. However, the very wide variation within each risk class indicates that needle complement in itself is not always a criterion of risk.

Table 1. Trees Used for Risk Analysis

Risk Class	Total Number Trees	D.B.H. in Inches			Height in Feet			Age in Years			No. Trees in Dunning Class					Number of Trees in Keen Class							
		Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.	Max.	Min.	1	3	4	5	7	2A	3A	3B	3C	4A	4B	4C	4D
1	16	32.1	38	24	106	124	81	356	560	208		4		12			3	1		6	3	3	
2	17	26.7	42	16	98	115	79					3	2	11	1		1	4		3	5	3	1
4	17	28.9	37	19	103	118	87	374	561	234	1	3	2	11		1	2	1	2	1	4	6	

Table 2. Average Number of Needle Fascicles by Years per Twig

	Average Number of Needle Fascicles by Years per Twig									Total	Standard Error
	1941	1940	1939	1938	1937	1936	1935	1934	1933		
Risk 1											
Top Crown	41.3	34.3	28.0	30.3	35.5	21.0	6.5	0.4	0.1	197.4	± 13.0
Mid Crown	37.2	29.6	27.6	29.7	32.3	23.7	7.5	0.3	0.2	188.1	± 11.3
Lower Crown	35.5	28.2	26.2	27.2	29.3	21.7	5.2	0.4	0.2	173.9	± 7.3
Risk 2											
Top Crown	40.6	30.5	18.6	26.8	35.1	21.9	7.5	0.1		181.7	± 11.2
Mid Crown	36.9	27.2	21.1	26.1	32.0	20.9	5.8	0.4		170.4	± 8.6
Risk 4											
Top Crown	22.8	19.6	16.9	19.3	22.9	13.7	3.6	0.3		119.1	± 13.1
Mid Crown	21.9	17.7	13.9	18.1	19.6	12.3	4.8	0.3	0.2	108.8	± 12.4

The average number of fascicles per twig in the top crown of the 50 trees sampled was 9 to 11 greater than in the mid crown. However, a number of trees did not fall in line with the average condition. On 5 of risk 1, 5 of risk 4, and 7 of risk 2, the needle complement was greater in the mid crown than in the top crown. Generally, when the complement was small in one portion of the crown, it was also small in the other portions. An exception to this was tree 87, risk 4, on which the complement was 167.2 and 66.4 in top and mid crown respectively.

The number of needle fascicles by years on risk 1, 2, and 4 trees is shown graphically in figure 1. The greatest number of needles was on the 1941 growth. The growth for 1939 had fewer needles than the preceding and following year. This is due to the fact that the 1939 needles were abnormally short and many were prematurely cast in 1940 and 1941. It was also observed that injured as well as abnormal needles were cast early. The graph indicates that some of the 1936, most of the 1935, and practically all of the 1934 needles had been cast. The needles then are retained for about 5 or 6 years. During the season of 1941, needle cast took place for the most part during August and September. The twigs on the risk 4 trees apparently retained their needles for as many years as those on the risk 1 trees.

The average needle complement per twig on 5 bark beetle infested trees in Dunning Class 5, risk 4, was practically the same as on 5 trees, Dunning Class 5, risk 4, but not infested. Two of the infested trees had complements equal to or greater than the average of risk 1 trees. The other 3 infested trees had unusually small complements.

Needle Length

The length of needles in the three risk classes is summarized by years in table 3. The data in this table were used to show graphically (fig. 2) the difference in needle length due to position in the crown. In all risk classes studied the average top crown needles were shorter than the mid crown needles, and the mid crown needles shorter than the lower crown needles. The significance of the differences is shown in table 4. On the low risk trees, the difference in length between top crown and mid crown needles was highly significant. On the risk 4 trees the difference was not significant. The greatest difference in length of needles between top and mid crown occurred on tree 93, risk 4, on which top crown needles were 4.82 inches in length and mid crown needles 5.34 inches in length or a difference of about an inch.

Severe drought conditions during the fall and winter of 1938 and spring of 1939 probably caused the 1939 needles to be abnormally short. This condition of short needles during that year is clearly shown in figure 2. The needles for the other years from 1935 to 1941 were nearly equal in length. The few needles remaining on twig growth for 1934 were considerably shorter, but not nearly as short as the 1939 needles. The effects of drought on needle growth of pines has been observed by a number of workers. Craighead (1941) noted that needles on white pine in a plantation near Carlisle, Pa. for the drought years of 1935 and 1936 were only $\frac{1}{2}$ to 1 inch long contrasted with

FIGURE 1. COMPARISON OF AVERAGE NUMBER OF NEEDLE FASCICLES PER YEAR PER TWIG IN UPPER TWO-THIRDS OF CROWN ON RISK 1, 2, AND 4 TREES

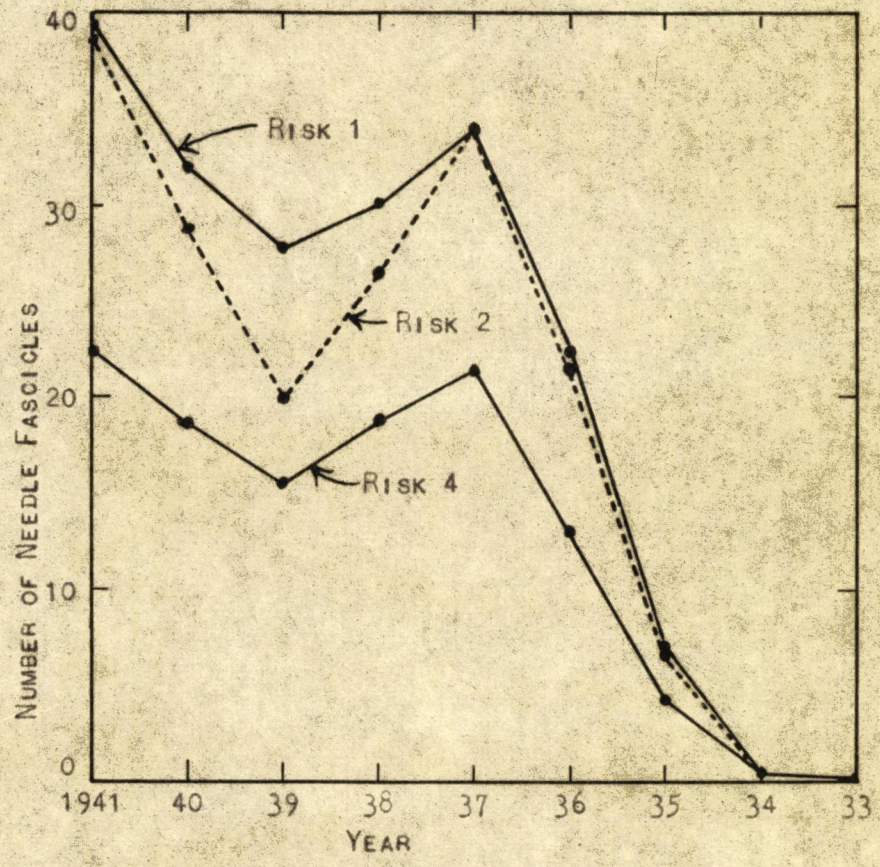
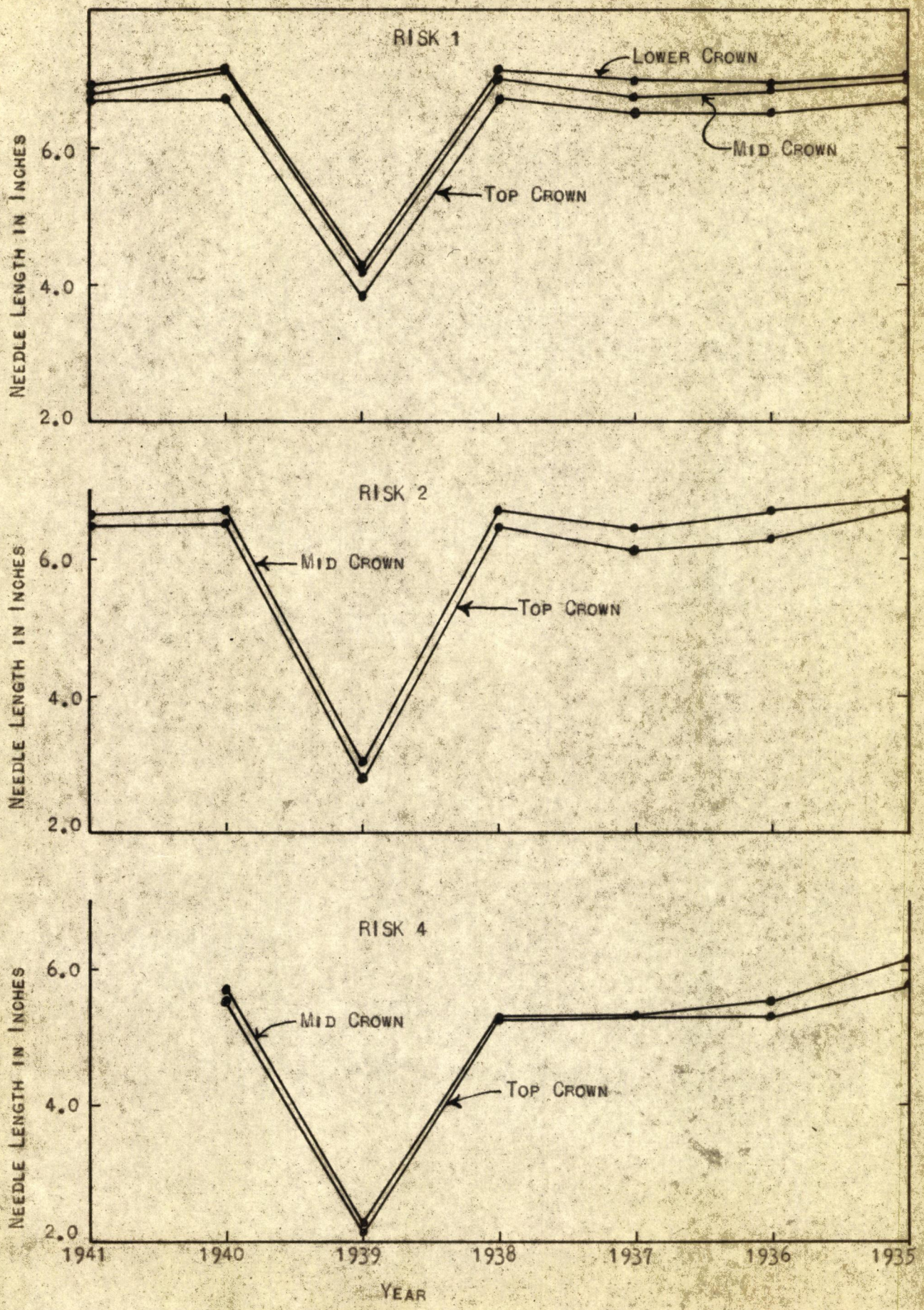


FIGURE 2. COMPARISON OF ANNUAL NEEDLE LENGTH FROM TOP, MID, AND LOWER CROWN ON RISK 1, 2, AND 4 TREES



older needles from 3 to 5 inches in length. The extreme drought during the summer of 1936 in Minnesota caused the white pine, Norway pine, and jack pine at the Cloquet Forest Experiment Station to have much shorter needles in that year than in 1935 (Schantz-Hansen and Joranson 1939). The effects of dry years on needle growth is also discussed by Büsgen and Muench (1929 English translation by Thomson).

Table 3. Comparison of Annual Needle Length on Top, Mid, and Lower Crown on Risk 1, 2, and 4 Trees

	Year & Average Length of Needles (inches)								
	1941	1940	1939	1938	1937	1936	1935	Average 1/	Standard Error 2/
Risk 1									
Top Crown	6.70	6.77	3.81	6.73	6.51	6.49	6.71	6.22	± 0.14
Mid Crown	6.82	7.12	4.19	7.01	6.75	6.81	7.00	6.47	± 0.15
Lower Crown	6.91	7.14	4.24	7.12	6.95	6.92	7.06	6.56	± 0.12
Risk 2									
Top Crown	6.48	6.52	2.79	6.44	6.12	6.28	6.75	5.84	± 0.17
Mid Crown	6.65	7.01	3.02	6.71	6.45	6.70	6.86	6.13	± 0.15
Risk 4									
Top Crown		5.53	2.14	5.24	5.30	5.31	5.79	4.91	± 0.13
Mid Crown		5.69	2.24	5.27	5.31	5.54	6.15	4.96	± 0.16

1/ The averages shown here were computed by adding the average of each tree for all years and dividing by the total number of trees.
2/ Standard error determined from average value of trees.

Table 4. Comparison of Needle Length in Top Crown and Mid Crown

	Risk Class	Top Crown	Mid Crown	t Value	Significance
Average Length of Needles	1	6.22	6.47	8.81	Very highly significant
	2	5.84	6.13	5.67	Very highly significant
	4	4.91	4.96	1.63	Not significant

The difference in needle length in relation to risk is analyzed in table 5. The difference in needle growth between risk 1 and risk 2 trees was not significant. Between risk 1 and risk 4 the difference was very highly significant.

Table 5. Comparison of Needle Length between Risk 1, 2, and 4 Trees

		Risk 1	Risk 2	Risk 4	Comparison	t Value	Significance
Average Length of Needles in Inches	Top Crown	6.22	5.81	4.91	1 with 2	2.79	Significant
					1 with 4	11.96	Very highly
	Mid Crown	6.47	6.13	4.96	1 with 2	2.31	Not significant
					1 with 4	9.32	Very highly

The average length of needles on 6 infested trees was somewhat better than the average of all risk 4 trees. One of these infested trees had needles which could be classed as long and 5 trees as medium. If needle length were arbitrarily divided into 3 classes the distribution of all trees would be as shown in table 6.

Table 6. Frequency Distribution of Trees According to Needle Length

	Long 6" or Longer	Medium 5" to 6"	Short Less than 5"
Risk 1			
Top Crown	10	6	
Mid Crown	12	4	
Risk 2			
Top Crown	9	6	2
Mid Crown	10	7	
Risk 4			
Top Crown	1	8	8
Mid Crown	1	8	8

The difference in needle length between the average of risk 1 and risk 4 trees is highly significant. However, it can be seen in table 6 that there is considerable variation in needle length within the risk class.

Needle length was also summarized by Dunning Classes and there appeared to be no difference due to tree class, however, the size of the sample was too meagre to be conclusive.

Needle Bundle Diameter

As a measure of needle coarseness, the needle bundle diameter was measured approximately $\frac{1}{4}$ inch from the base of the needle fascicle by means of a vernier caliper with scale divisions of 0.1 mm. Two or three fascicles

were measured from each year's needle growth on each twig and the average recorded. These measurements are summarized in table 7. There proved to be very little difference between the average needle bundle diameter of the three risk groups. The significance of the annual differences between the average diameters of the risk groups is shown in table 8. Although the differences between the average of risk 1 and risk 4 were small in amount, the difference between both mid and top crown was highly significant. The difference between the average of risk 1 and risk 2 in mid crown was highly significant, but the difference in top crown was not significant.

Table 7. Comparison of Needle Bundle Diameter of Top, Mid, and Lower Crown from Risk 1, 2, and 4 Trees

	Year and Average Needle Bundle Diameter in mm.							Average	Standard Error
	1941	1940	1939	1938	1937	1936	1935		
Risk 1									
Top Crown	1.89	1.88	1.80	1.88	1.82	1.93	1.93	1.87	± 0.029
Mid Crown	1.88	1.85	1.79	1.85	1.82	1.88	1.91	1.86	± 0.027
Lower Crown	1.82	1.79	1.74	1.80	1.79	1.85	1.89	1.80	± 0.027
Risk 2									
Top Crown	1.92	1.85	1.78	1.86	1.81	1.86		1.85	± 0.031
Mid Crown	1.86	1.84	1.75	1.79	1.76	1.83		1.81	± 0.031
Risk 4									
Top Crown		1.81	1.74	1.79	1.74	1.81	1.94	1.80	± 0.035
Mid Crown		1.78	1.68	1.74	1.73	1.81	1.90	1.76	± 0.032

Table 8. Comparison of Needle Bundle Diameter between Risk 1, 2, and 4 Trees

		Risk 1	Risk 2	Risk 4	Comparison	t Value	Significance
Average Diameter of Needle Bundles in mm.	Top Crown	1.87	1.85	1.80	1 with 2	2.55	Not significant
					1 with 4	4.29	Very highly
	Mid Crown	1.86	1.81	1.76	1 with 2	4.65	Very highly
					1 with 4	5.05	Very highly

Although the "t" test showed a difference in needle bundle diameter due to risk, the variation of needle bundle diameter within each risk class was great. For example, in risk class 1 the variation was from 2.01 mm. on tree 1057, Keen 4B; to 1.65 mm. on tree 1682, Keen 3B. In risk class 4 the variation was from 2.16 mm. on tree 39, Keen 4C; to 1.62 mm. on tree 93, Keen 3A. There appeared to be no relation of needle coarseness to needle complement or tree class.

The data in table 7 indicate rather consistently that the needles on the average of trees are coarser in the top crown than in mid crown, however this difference is small. Of 49 trees on which needle bundle diameter was measured, the needles were greater in diameter in top crown on 61 percent, in mid crown on 29 percent, and equal on 10 percent.

Twig Growth

Twig growth is differentiated into annual nodes by bud scales at the internodes. After the bud scales have sloughed off, the internodes are marked by a constriction on the twig. On the faster growing trees the internodes were not distinct beyond approximately 25 years, but on the very slow growing trees the internodes are quite distinct considerably beyond this period. The twigs, 5 from each top, mid, and lower crown, from which needles were removed for measurement were also used for twig growth measurements.

These twig growth measurements from 1917 to 1941 are summarized in table 9. The average annual growth during the 25 years on risk 1 trees from top, mid, and lower crown were 0.80, 0.72, and 0.70 inches respectively. On the risk 4 trees the annual growth was 0.58 inches in top crown and 0.57 inches in mid crown. The difference between the average growth both top and mid crown of risk 1 and risk 4 trees proved to be highly significant (table 10).

Table 9. Annual Twig Growth from Top, Mid, and Lower Crown on Risk 1 and Risk 4 Trees

	Year and Length of Node in Inches													
	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Risk 1														
Top Crown	.96	.96	.88	.78	.80	.88	.87	.79	.60	.89	.91	.93	.94	.71
Mid Crown	.86	.83	.74	.71	.70	.83	.74	.72	.57	.82	.81	.85	.81	.64
Lower Cr.	.87	.81	.71	.70	.68	.80	.74	.76	.54	.83	.78	.78	.77	.63
Risk 4														
Top Crown	.81	.79	.75	.68	.67	.71	.72	.66	.51	.72	.69	.68	.63	.48
Mid Crown	.78	.79	.70	.65	.60	.69	.64	.65	.49	.75	.67	.65	.64	.49

Table 9 (Continued)

	Year and Length of Node in Inches												Standard Error 1/
	31	32	33	34	35	36	37	38	39	40	41	Average	
Risk 1													
Top Cr	.70	.62	.76	.70	.65	.83	.84	.75	.86	.59	.83	.80	± .058
Mid Cr	.66	.57	.68	.62	.63	.78	.72	.67	.75	.56	.70	.72	± .048
Lower	.67	.56	.69	.58	.64	.75	.70	.66	.70	.55	.68	.70	± .041
Risk 4													
Top Cr	.53	.44	.54	.49	.47	.55	.53	.46	.47	.33	.46	.58	± .045
Mid Cr	.55	.46	.53	.48	.49	.54	.52	.45	.46	.34	.44	.57	± .039

Table 10. Comparison of Twig Growth Rate between Risk 1 and Risk 4 Trees, 1917 to 1941

		Risk 1	Risk 4	t Value	Significance
Average Annual Growth in Inches	Top Crown	0.80	0.58	13.08	Very highly significant
	Mid Crown	0.72	0.57	10.10	Very highly significant

The average annual growth from the different parts of the crown is shown in figure 3. The twigs in the top crown of risk 1 trees were growing 10 percent faster than twigs from mid crown of the same trees. Difference in growth rate between top and mid crown of risk 4 trees was negligible, however the difference proved to be significant. The difference in growth rate between top crown and mid crown of risk 1 trees proved to be very highly significant (table 11).

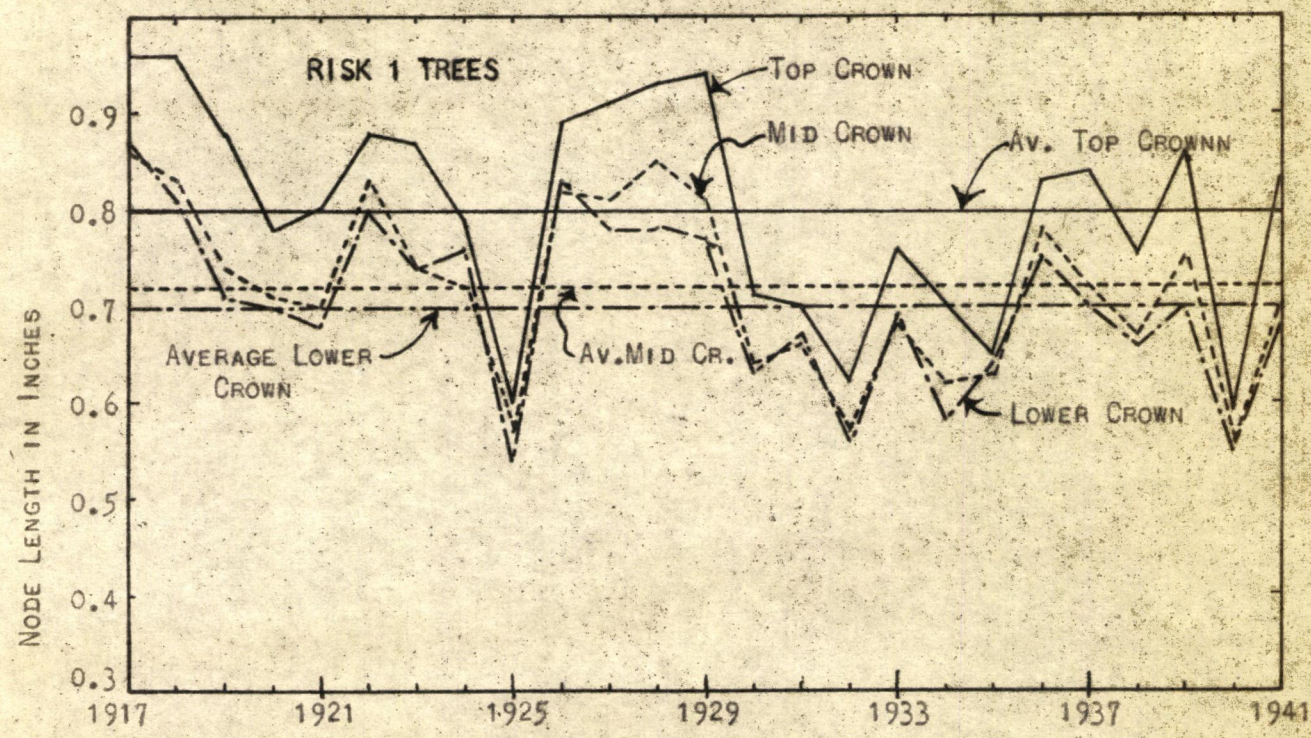
Table 11. Comparison of Twig Growth Rate between Top and Mid Crown on Risk 1 and Risk 4 Trees

		Top Crown	Mid Crown	t Value	Significance
Average Annual Growth in Inches	Risk 1	0.80	0.72	11.60	Very highly significant
	Risk 4	0.58	0.57	2.39	Significant

The growth pattern of the risk 1 and risk 4 trees, both mid and top crown is very similar (fig. 3) except that growth on the risk 4 trees has been on a decline during the 25 years. Growth for the years 1925, 1932, and 1940 in both risk classes was considerably below the 25-year average. The nodes for these years were quite conspicuous on nearly all twigs. Growth for 1940 on the risk 4 trees was considerably below the growth for 1925. The risk 4 trees showed some recovery in growth in 1941 but growth was considerably below the 25-year average. The 1941 growth on the risk 1 trees was a little better than the 25-year average.

Growth in the top crown of risk 1 and risk 4 trees during the past 25 years is compared graphically in figure 4. At no time during the 25-year period did the twig growth on the risk 4 trees equal that of the risk 1 trees. On the trees analyzed by Hall (1941) at Hat Creek in 1940 the growth was similar on high and low risk until 1933 when there was a substantial change in growth. At Black's Mountain after the poor year of 1925 there was, however, an increase in the difference between the level of growth on the trees of the two risk groups.

FIGURE 3. COMPARISON OF ANNUAL TWIG GROWTH RATE IN TOP, MID AND LOWER CROWN OF RISK 1 AND RISK 4 TREES



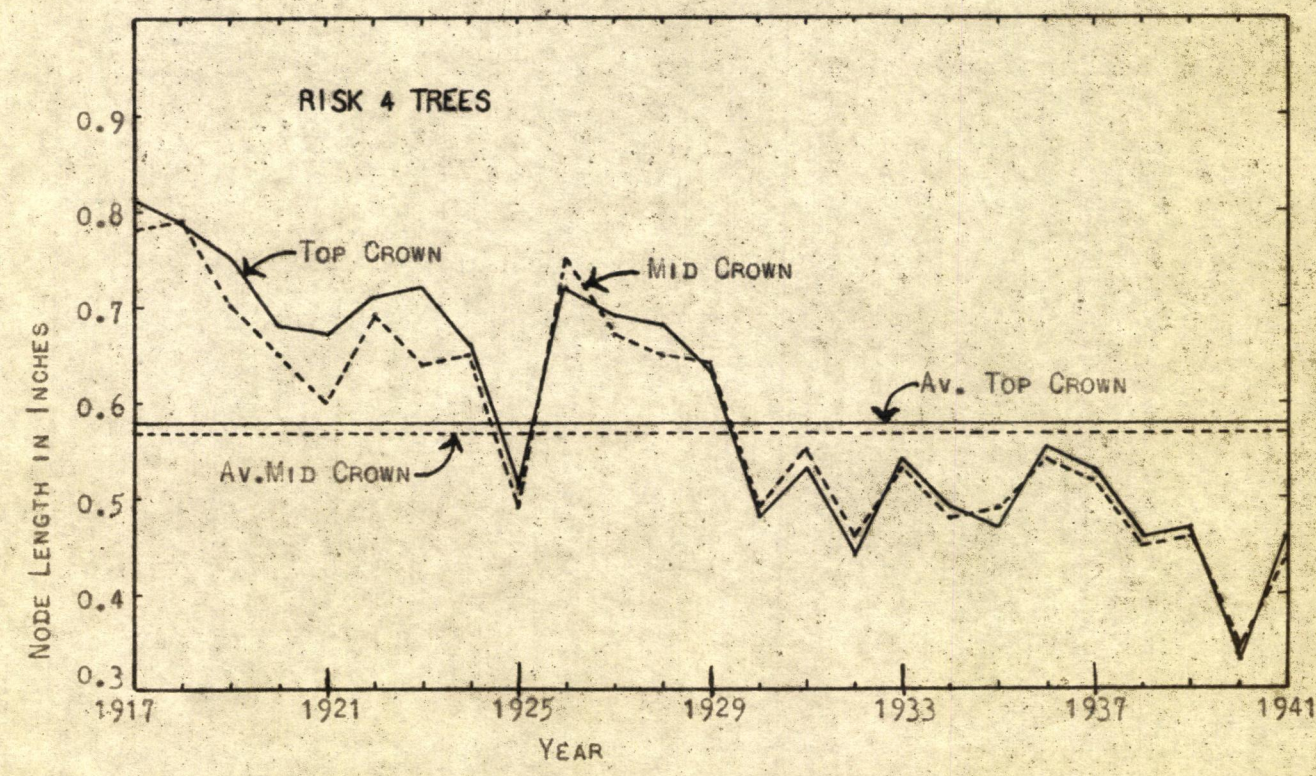
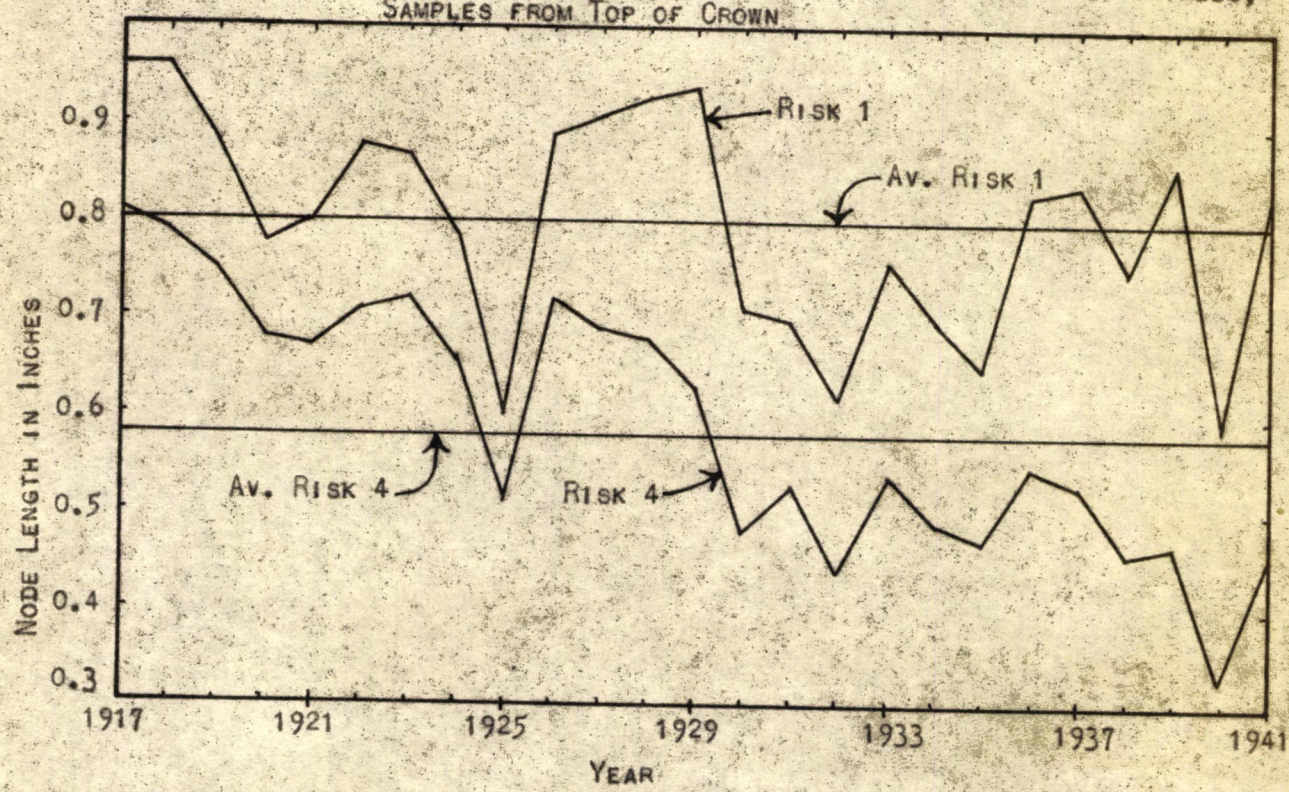


FIGURE 4. COMPARISON OF TWIG GROWTH RATE OF RISK 1 AND RISK 4 TREES, SAMPLES FROM TOP OF CROWN



The variation in twig growth between trees in the same class was great, and it was evident that the rate of growth of sample twigs is not an indicator of risk in all cases. Individual twig growth on trees with a very full crown with a large number of twigs was apt to be less than on trees with a thinner crown and a limited number of twigs. Twigs on the thinner crowns frequently were fast growing. The twig growth measurement as a criterion of risk is unsatisfactory because it does not measure the sum of growth, but merely growth on individual twigs. Trees 1443 and 1517 which had the slowest and fastest growing twigs of risk 1 trees illustrate this very well. Average annual twig growth on tree 1443 with a full crown was 0.49 inches while on tree 1517 with a thinner crown average growth was 1.41 inches. Average annual growth for each tree in risk class 4 varied from 0.37 inches on an infested tree (tree 1) to 1.11 inches on a green tree (tree 39). The best growth on an infested tree was 0.87 inches (tree 5) which is better than the average of risk 1 trees.

The frequency distribution of trees by 1/10 inch growth classes is shown in table 12. The risk 4 trees tend to group in the slower growth classes while the risk 1 trees tend to group in the better growth classes.

Table 12. Frequency Distribution of Trees by 1/10 Inch Average Twig Growth Classes During the Period 1917 to 1941

	Number of Trees by 1/10 Inch Growth Class										
	.31 to .40	.41 to .50	.51 to .60	.61 to .70	.71 to .80	.81 to .90	.91 to 1.00	1.01 to 1.10	1.11 to 1.20	1.21 to 1.30	1.31 to 1.40
Risk 1											
Top Crown		1	2	4	1	3	3	1			1
Mid Crown		2	2	6	2	1	1	2			
Lower Crown		1	1	8	4			1	1		
Risk 4											
Top Crown	2	6	5	1	1	1			1		
Mid Crown	2	4	4	4	2		1				

Twig Diameter

On the twigs from which needle and twig measurements were taken, twig diameter also was measured with a pair of callpers on the nodes of years 1915, 1920, 1925, 1930, and 1935. The average of these measurements is shown in table 13 and figure 5. The data are conclusive that twigs in the top crown generally are larger than in mid crown and larger in mid crown than in the lower crown. There were a few trees in the risk 4 group that did not follow this relationship. The average diameter growth of the top crown twigs of risk 4 trees was considerably below the level of growth of twigs from the lower crown of the risk 1 trees.

FIGURE 5. COMPARISON OF TWIG DIAMETER ON RISK 1 AND RISK 4 TREES

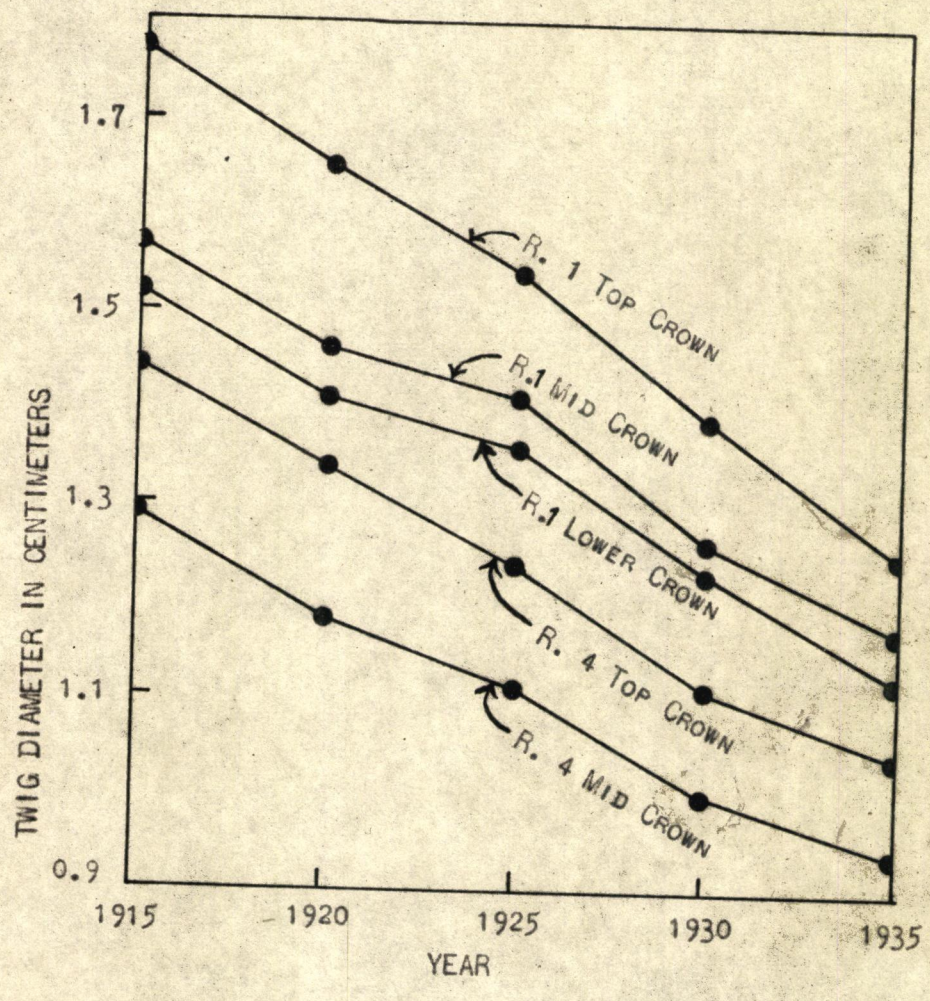


Table 13. Comparison of Twig Diameter on Risk Class 1 and 4 Trees, Samples from Top, Mid, and Lower Crown

	Year and Average Twig Diameter in Centimeters outside Bark					
	1915	1920	1925	1930	1935	Average
Risk 1						
Top Crown	1.77	1.65	1.54	1.39	1.25	1.52
Mid Crown	1.57	1.46	1.41	1.28	1.17	1.38
Lower Crown	1.52	1.41	1.36	1.23	1.12	1.32
Risk 4						
Top Crown	1.44	1.34	1.24	1.11	1.04	1.23
Mid Crown	1.29	1.18	1.11	1.00	0.94	1.10

Twig coarseness within each risk class varied considerably from tree to tree (table 14). Some of the risk 1 trees had small twigs and some of the risk 4 had large twigs. Here again some of the thin crowned trees with few twigs but each twig growing vigorously showed better twig diameter growth than some full crowned trees with an abundance of twigs.

Table 14. Frequency Distribution of Trees by 1/10 Centimeter Classes, Average Diameter Measurements at 5-year Intervals from 1915 to 1935

	Number of Trees by 1/10 Cm. Twig Diameter Classes										
	0.81 to 0.90	0.91 to 1.00	1.01 to 1.10	1.11 to 1.20	1.21 to 1.30	1.31 to 1.40	1.41 to 1.50	1.51 to 1.60	1.61 to 1.70	1.71 to 1.80	1.81 to 1.90
Risk 1											
Top Crown					4	1	1	4	2	4	
Mid Crown				3	3	2	4	3	1		
Lower Cr.			1	1	6	6	1				1
Risk 4											
Top Crown		1	1	4	8	2			1		
Mid Crown	1	4	4	2	5	1					

Radial Growth on the Stem

From each tree a wedge was taken from the stump, a disc from near the 10-inch diameter limit, and a disc from near the top. It would have been desirable to have had discs from a standard point in the mid bole, but this was impossible because the section would have come in the merchantable part of the stem. Most of the sections were taken between the 10 and 16 inch diameter limits for the mid bole sample. Since the overmature trees frequently do not have a central dominant leader, it was necessary to take a disc from the most

dominant branch for the top section. The top sections usually were between the 3 and 5 inch diameter limits. Annual ring growth measurements were taken principally for comparison with twig growth and not for comparison of ring growth in low and high risk trees. Because of the unequal representation of the tree classes in the risk 1 and risk 4 trees and because of the small number of trees in the sample the data may not be conclusive.

The annual rings were measured with a core measuring instrument after the sections had been stained with a weak solution of phloroglucinol. This stain aided a great deal in making the very narrow rings on the risk 4 trees more visible. The rings on the risk 1 trees were clearly defined and all trees showed a definite growth pattern with the rings produced in 1912, 1924, and 1939 quite distinctive. The ring growth on the risk 4 trees was quite placid. It was quite evident that rings were missing on some of the trees, and because of the lack of key rings it was impossible to date the rings on most of the risk 4 trees. In order to get some sort of measurement, the missing rings were disregarded and each ring was measured back to the thirtieth ring, which may or may not have been the ring for 1912. The fact that the rings were not accurately matched with the correct years probably accounts for some of the smoothing out of the curves for the risk 4 trees in figure 6.

The radial growth in top, mid, and base of bole of risk 1 and risk 4 trees is shown in figure 6. The most striking difference in growth is that the radial growth rate on the mid bole of risk 1 trees was approximately 46.5 percent greater than at the stump. Radial growth on the mid bole of risk 4 trees was 11.1 percent less than on the stump. The difference in average growth rate at stump and mid bole proved to be highly significant by the "t" test both on risk 1 and risk 4 trees. The rather large standard errors indicate that these differences, at least on the risk 4 trees, can be accounted for by the sampling error. (Standard errors are shown in figure 6.) That the difference on the risk 1 trees is true is indicated by the amount of the difference and by the fact that only 1 of the 16 trees was growing faster at the stump than at mid bole.

The growth of the risk 1 and risk 4 trees is compared in figure 7. Growth has been on a decline during the past 3 decades, with some improvement in growth on the risk 1 trees since 1936. The risk 4 trees failed to show this improvement in 1936 and growth has continued to decline. There was no significant difference in growth rate on the stump between risk 1 and risk 4 trees from 1912 to 1935. However, since that date the difference has been highly significant. During the 30 years, growth on the mid bole of risk 1 has been much better than on mid bole of the risk 4 trees.

A much more complete study of ring growth on cores taken at D.B.H. on live and beetle killed trees by Keen (1941) has shown that growth on beetle killed trees was more placid during the 50 years preceding death and that growth was inferior over a long period of time. The growth rate on the stump of the present risk 4 trees, while complacent, was not inferior except during the past 8 years. Growth rate on the mid bole of the risk 4 trees was inferior during the 30-year period.

FIGURE 6. COMPARISON OF RADIAL GROWTH ON TOP AND MID BOLE AND STUMP OF RISK 1 AND RISK 4 TREES

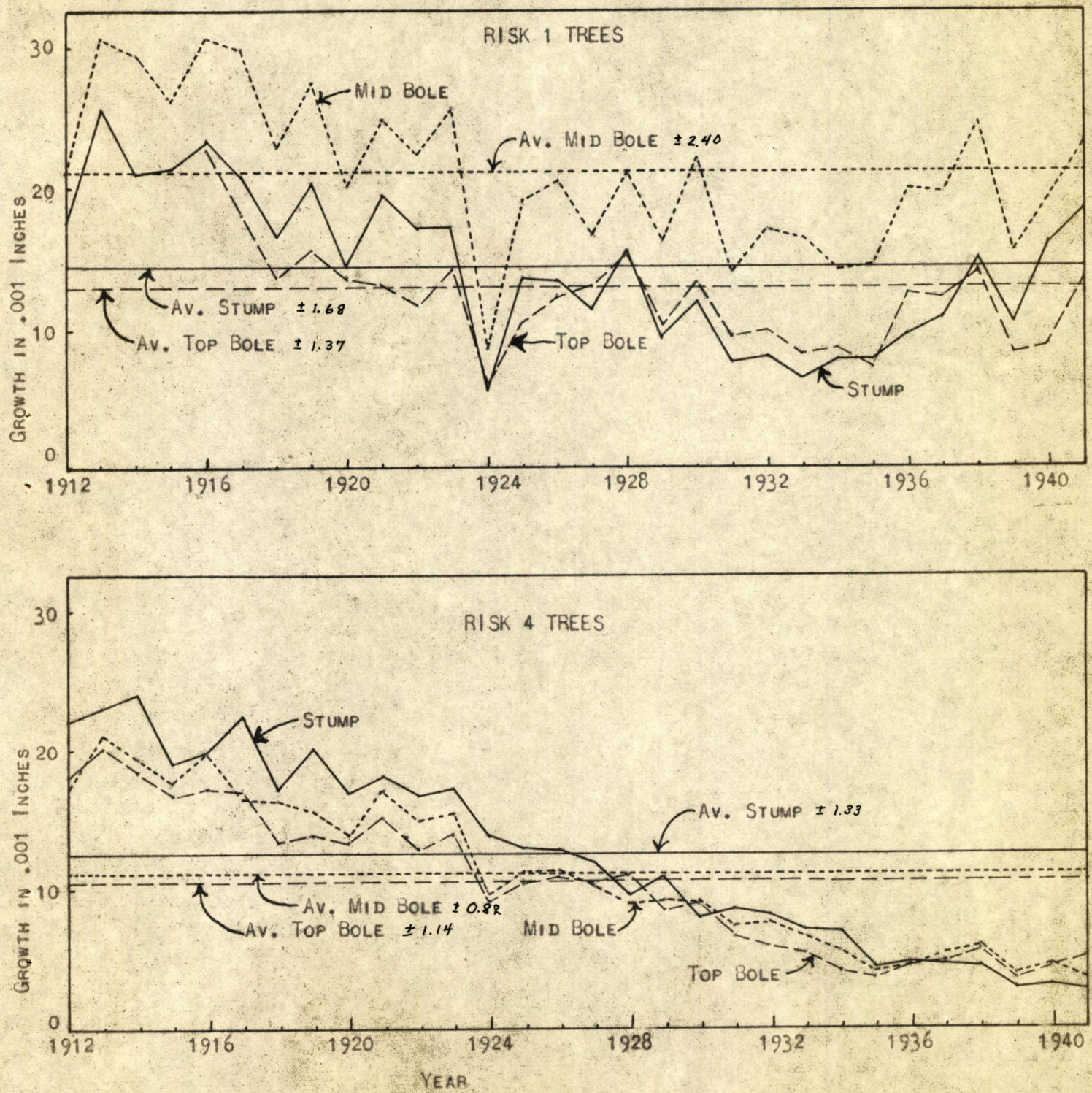
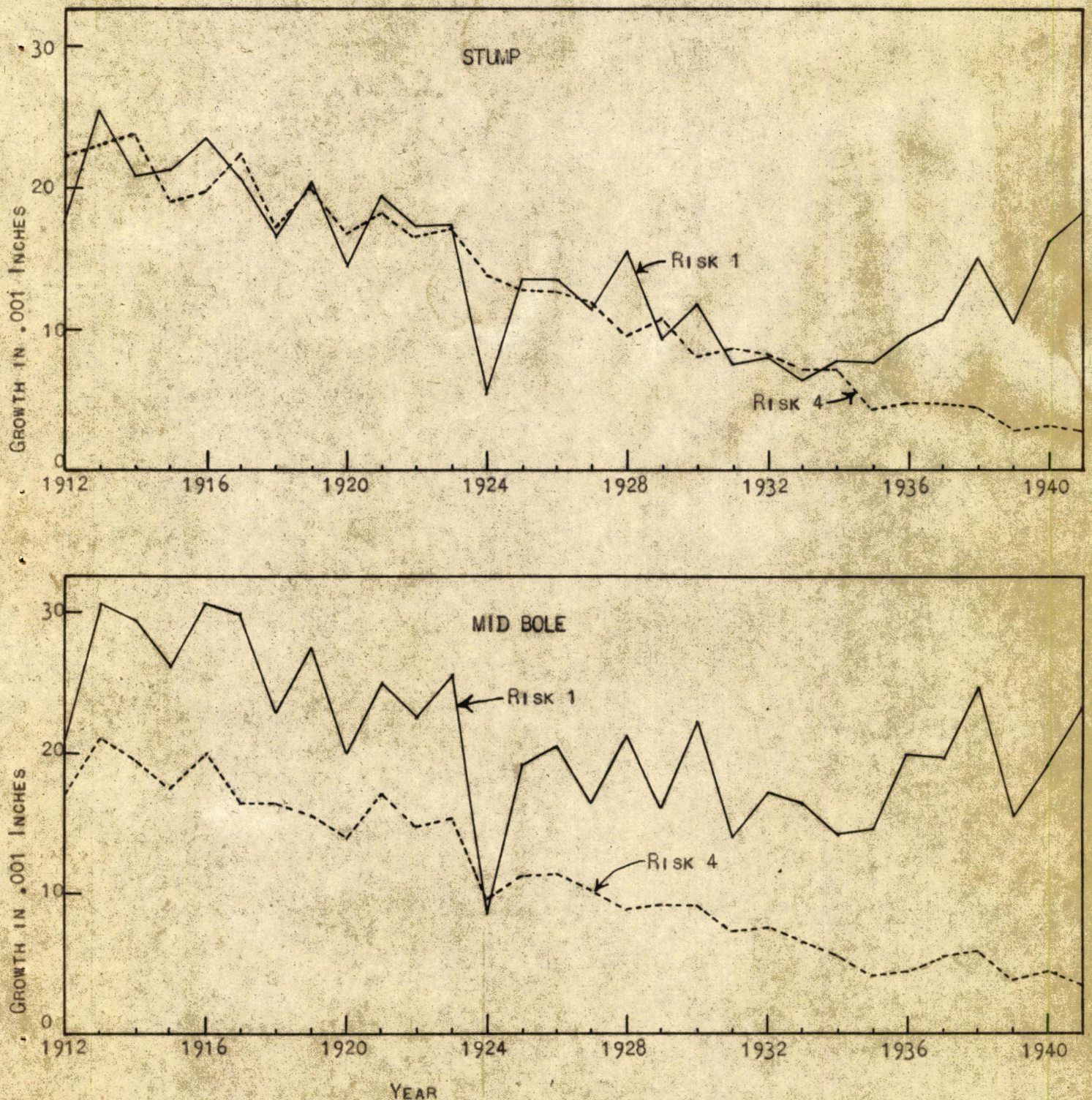


FIGURE 7. COMPARISON OF ANNUAL RADIAL GROWTH RATE OF RISK 1 AND RISK 4 TREES



Ring growth rate in the top bole was slightly less than at the stump. The ring growth for the most part was eccentric on the top bole and it was impossible to get an accurate measurement of growth. Some of the rings were very narrow and undoubtedly a number were lost.

If the annual increase in cross sectional area of a stem is the same throughout its length, the width of the annual ring must increase from the stump to the top because the circumference diminishes from the stump upward. Consequently the annual rings are as a rule widest immediately below the living crown (Busgen and Muench 1931). Supposedly the width of the ring falls off with each branching. Therefore the width of the ring at mid bole being greater than at stump as on risk 1 trees is a normal condition, and the width of the ring at mid bole on risk 4 trees being similar to the width on the stump is an abnormal condition.

The sections referred to as from midbole in the present study were usually well up in the living crown. In future studies it would be well to take sections at various points in the stem to determine more fully this relation of ring growth between risk 1 and risk 4 trees.

Relation of Annual Twig and Ring Growth

The fluctuation in annual twig growth lags, for the most part, one year behind the fluctuation or response in ring growth to weather. This lag is clearly shown in figure 8 where the top horizontal scale of years from which twig growth is plotted is shifted one year behind the bottom horizontal scale from which annual ring growth is plotted. By plotting the data thusly, the two curves show very similar patterns. A poor ring growth occurred in 1924 but the poor shoot growth did not occur until 1925. Likewise the small ring of 1939 was followed by short shoots in 1940.

The explanation given by Busgen and Muench (1931) for the poor shoot growth lagging 1 year behind unfavorable weather is that shoot growth is produced from reserve materials stored up the previous season. Wet years, therefore, do not have a favorable effect on the height growth until the following year. Diameter increment supposedly depends upon the current production of food and is therefore influenced only by the current weather.

Seasonal Growth of Needles and Shoots

Shoot and needle growth were measured at weekly intervals on 3 twigs from each of 4 trees 7 to 14 feet tall to determine the time that needle and shoot growth take place in the vicinity of the Black's Mountain Experimental Forest. The average accumulative growth is shown in figure 9. Measurements were not started until June 17 at which time shoot growth was well under way. Shoot growth was nearly complete by July 7. Most of the needle growth took place from June 23 to August 25 or after most of the shoot growth was completed. The growth season of 1941 was abnormally cold and somewhat above normal in precipitation, therefore the period of growth may not have been typical of all years.

FIGURE 8. COMPARISON OF RING GROWTH WITH TWIG GROWTH, RISK 1 TREES

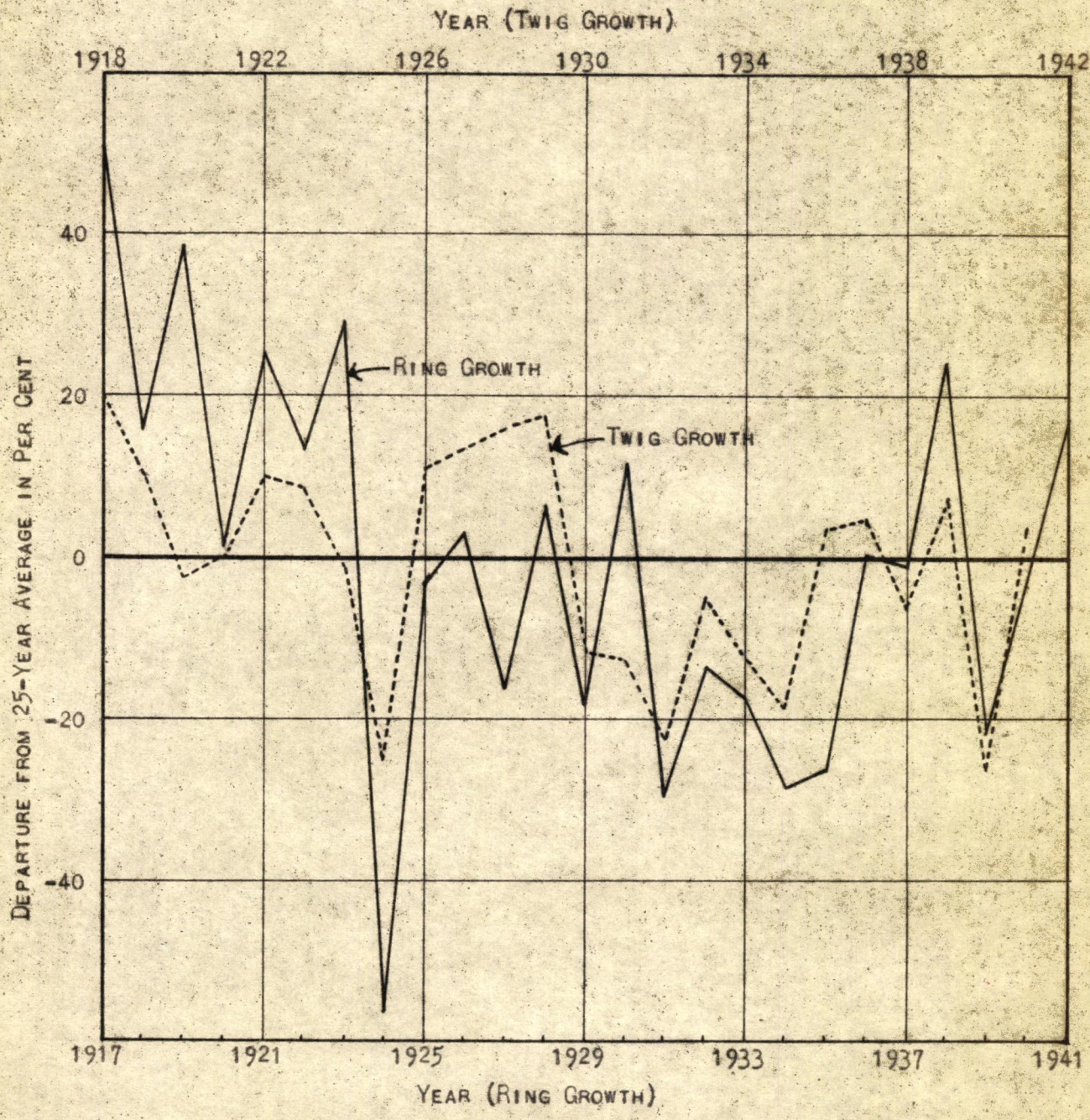
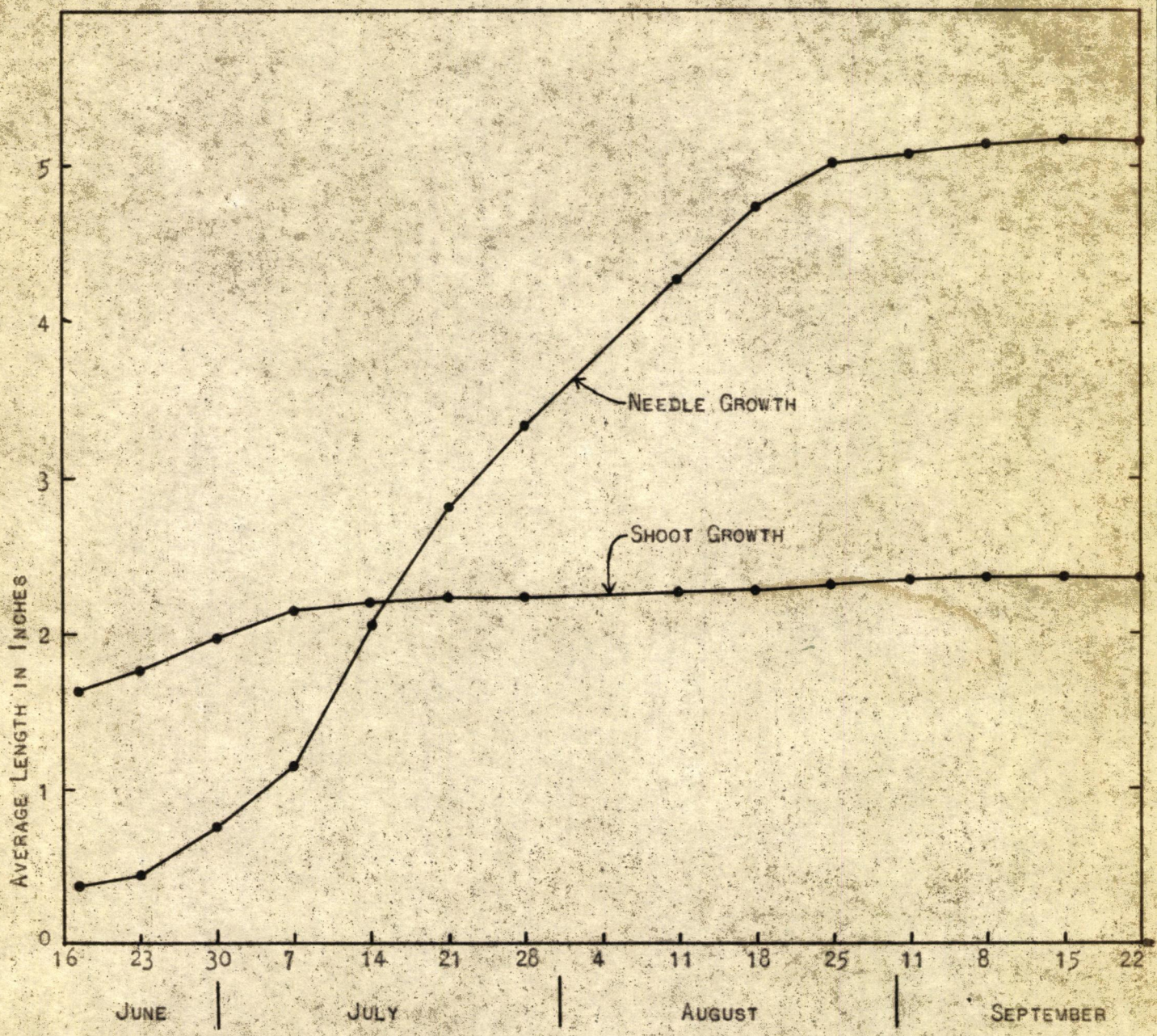


FIGURE 9. AVERAGE NEEDLE AND SHOOT GROWTH ON 4 PONDEROSA PINES, 7 TO 14 FEET IN HEIGHT, 3 SAMPLE TWIGS FROM EACH TREE



A recent article by Fowells (1941) has added a great deal to the information on the period of growth of ponderosa pine. In the Sierra Nevada he found that the beginning of radial growth precedes the beginning of height growth by approximately one month. At the time height growth ended, 84 percent of the radial growth had occurred. The stage of seasonal growth may be estimated roughly by the development of the needles. At the time of needle emergence from the fascicle sheath, ponderosa pine had completed 50 percent of its seasonal growth. MacDougal (1938) states that there is an increase in diameter in the spring due to hydration of the sapwood and it may be possible that some of the early radial growth reported by Fowells is the swelling of the tissues due to this phenomenon.

Discussion of Growth Study Results

Growth on the main stem, needles, and shoots on 16 risk 1 and 17 risk 4 trees have been measured and summarized independently of each other to see how growth differed due to risk and due to position on the tree. The purpose of this discussion is to attempt to provoke thought on the relation of growth on one portion of the tree to another. First of all it is assumed that adverse or unfavorable weather conditions cannot affect one growing tissue or growth point without similarly affecting either directly or indirectly other growing tissues. These effects quite often are not concurrent and the response of growth in one tissue may lag a year behind the response in another.

The number of needles produced on a shhot is predetermined in the bud the preceding summer or the summer that the bud is set (Busgen and Muench 1931). Therefore the number of needles on a node is influenced by the weather and growth conditions of the previous season and not the current season. On this basis one would expect fewer needles in 1940 than in 1939 because of the unfavorable weather in 1939. This proved to be true on the trees analyzed by Hall at Hat Creek in 1940. Because the 1939 needles were abnormally short, many were prematurely cast, which made it impossible to verify this on the trees analyzed at Black's Mountain in 1941.

Since most of the needle growth takes place after shoot growth is completed and after diameter growth on the stem is more than 50 percent completed, needle length then may be expected to be influenced by the current weather. Needle diameter varied little from year to year, although there was a small decrease in needle diameter in the unfavorable year of 1939. Busgen and Muench (1931) mention that growth in length and thickness of pine needles has been detected over a number of years. The amount of growth is not mentioned.

Shoot growth is supposedly formed from reserve material produced the previous season and therefore is not dependent upon the current weather but mainly upon the climate of the preceding summer. This lag of response of shoot growth behind ring growth has been shown. The shoots are produced in the spring when there is an abundance of moisture from the winter and spring snow and rain and therefore moisture during the current growing season of the

shoots is not apt to be a limiting factor. In the eastside pine type, moisture usually is not a limiting factor until late spring or summer. Fowells (1941) found that diameter growth starts approximately a month before shoot growth and if it is true that shoots depend upon reserve food for growth, ring growth, because it starts first in the spring, should also be influenced by stored food and conditions of the previous season. However, numerous studies of ring growth in areas where moisture is a limiting factor have shown that rings are often reliable indicators of current weather.

Food for growth in all parts of the tree is dependent upon the green needles. The amount of food produced, then, is limited by the amount of leaf surface. A tree with a small amount of total leaf surface theoretically would not be a fast growing tree regardless of the length and number of needles per twig. The leaf area is in balance with the roots and other growing parts of the tree. Any adverse condition then is apt to upset this balance temporarily; but since one growing part is dependent upon another, this balance must be adjusted. The adjustment in the crown to adverse conditions may be through a reduction in the number of needles, decrease in length or diameter of needles, or a reduction in the number of needle bearing twigs. This is indicated by the fact that there is a reduction in leaf area on the average of risk 4 trees from the average of risk 1 trees. This study shows that this reduction in leaf area may be accomplished by a general reduction in needle length, needle number, and number of needle bearing twigs, or it may be accomplished by a reduction of only one or more of the possibilities. For example, some of the infested risk 4 trees had long needles and good needle complement per twig, but a small number of needle bearing twigs. Likewise a few risk 1 trees had short needles, and small needle complements per twig, but a large number of needle bearing twigs which provided the tree with a large total leaf surface. This variation in crown characteristics can be due to either or both inheritance or environment. The numerous reactions that a tree may have to its environment must vary with the adaptive capacities inherent in the tree. The variation in reactions in individual trees has been observed on paired trees that apparently were growing in the same environment, of the same age, and similar in all outward respects except that one tree is vigorous and the other is decadent. One explanation for the difference is through inheritance. One may have inherited a better root system or a better crown and has been better able to cope with the environment, or one may have a greater resistance to Matsucoccus, fungi, or it may have one or more of many other superior qualities. This variation in trees may also be due to local environmental or edaphic conditions that are not apparent to the observer.

Much attention has been given by agriculturists to the development of desired characteristics of cultivated plants through selection and crossing. Two familiar examples of their accomplishments are wheat varieties that are resistant to Hessian fly, and corn that has a large root system and a small stalk and is therefore resistant to drought. Since geneticists have found great individual differences in the characteristics of annual plants, similar differences probably also exist between individual ponderosa pines.

Insects and Fungi

Needle injury caused by defoliating insects was estimated when needle length was measured. Nearly all of the 50 trees that were analyzed showed at least a few injured needles. Approximately 1.5 percent of the needles on the risk 1 trees were injured and 4.5 percent of the needles on the risk 4 trees. This injury consisted of portions of the needles being eaten and notches eaten into the edges of the needles killing the outer ends of the needles and appeared to be the work of adult Coleoptera. The shoots of certain trees had some old top or pitch moth injury, but little current work was found. The part played by Matsucoccus and Melanophila californica in high risk is outside the realm of the present study and is not mentioned here.

The dwarf mistletoe, Arceuthobium campylopodum Engelm., is very common on many of the pines of all ages and is undoubtedly causing considerable damage. Hypodermella medusa Dearn. is a needle fungus which has been known to contribute to high risk on a few trees. A staining fungus, Leptographium lundbergii, was found on the roots of some trees. These trees were examined by Dr. W. W. Wagener, but as yet he has not determined the importance of the fungus.

SUMMARY AND CONCLUSIONS

High risk and low risk ponderosa pine trees were felled and analyzed at Black's Mountain Experimental Forest during the summer of 1941 as part of the project on the causes of risk. In all, 16 risk 1, 17 risk 2, and 17 risk 4 trees were analyzed. The trees were for the most part overmature, were 16 to 42 inches D.B.H., and 79 to 124 feet high. Six of the risk 4 trees were infested with subcortical insects at the time of the analysis. The measurements taken on the total of 50 trees are summarized in the following table:

	Top Crown		Mid Crown 1/		Lower Crown 2/	
	Risk 1	Risk 4	Risk 1	Risk 4	Risk 1	Risk 4
Number of needle fascicles per twig	197.4	119.1	188.1	108.8	173.9	
Needle length in inches	6.22	4.91	6.47	4.96	6.56	
Needle diameter in mm.	1.87	1.80	1.86	1.76	1.80	
Annual twig growth in inches, 1917-40	.80	.58	.72	.57	.70	
Twig diameter in cm.	1.52	1.23	1.38	1.10	1.32	
Annual radial stem growth in inches, 1912-41	.0128	.0105	.0211	.0112	.0144	.0126

1/ For radial stem growth this column should be headed "mid bole"
2/ For radial stem growth this column should be headed "stump"

Briefly, the results and conclusions of the study are as follows:

1. The average needle complement per twig in the top and mid crown of the risk 1 trees was 69 percent better than that on the risk 4 trees. This difference between the risk 1 and 4 trees was very highly significant and between the risk 1 and risk 2 not significant. The variation in number of needles per twig from tree to tree within each risk class was great.

2. The average number of needles per twig was greater in the top crown than in the mid crown by 5 percent on risk 1, 7 percent on risk 2, and 9 percent on risk 4.

3. Needles for the most part were retained for about 5 to 6 years, both on high and low risk trees.

4. The average needle length in top and mid crown of the risk 1 trees was 29 percent greater than that of the risk 4 trees. The difference between risk 1 and risk 4 trees was very highly significant. Between risk 1 and risk 2 the difference was significant in top crown but not significant in mid crown. The variation from tree to tree within each risk class was great.

5. The average length of needles in the mid crown was greater than that in the top crown on risk 1 by 4 percent, on risk 2 by 5 percent, and on risk 4 by 1 percent. On risk 1 and 2 the difference was very highly significant and on risk 4 not significant.

6. The 1939 needles were abnormally short, probably due to a dry season. Many of these short needles were prematurely cast.

7. The average needle bundle diameter in the top and mid crown of the risk 1 trees was 5 percent greater than that of the risk 4 trees. The difference between risk 1 and risk 4 and between risk 1 and risk 2 was very highly significant except between risk 1 and risk 2 in the top crown.

8. The needles in the top crown are a little coarser than in the mid crown.

9. The average annual twig growth in the top and mid crown during the past 25 years of the risk 1 trees was 32 percent better than that of the risk 4 trees. This difference in growth was very highly significant. The variation from tree to tree within each risk class was great.

10. Average annual twig growth of risk 1 trees was 11 percent better in top crown than in mid crown. The difference in twig growth betweeh top and mid crown of the risk 4 trees was not significant.

11. Twig growth rate on the risk 4 trees has been on a decline throughout the past 25 years. While the growth on the risk 1 trees has been on somewhat of a decline during that period, the risk 1 trees have shown recovery since 1936 not shown by the risk 4 trees. At no time during the 25-year period did twig growth of the risk 4 trees equal that of the risk 1 trees.

12. The average twig diameter in top and mid crown of the risk 1 trees was 24 percent greater than that of the risk 4 trees.

13. Twig diameter increases from the base of the crown upward.

14. The average annual radial growth during the past 30 years at the mid bole of the risk 1 trees was 46.5 percent greater than that at the stump. Mid bole growth on the risk 4 trees was 11.1 percent less than the growth at the stump. Literature on tree growth indicates that annual radial growth on the stem is normally the greatest just below the living crown. Therefore the risk 1 trees were growing in a normal manner and the risk 4 trees in an abnormal manner.

15. Radial growth has been on a decline throughout the past 30 years. This decline has been greater on the risk 4 trees than on the risk 1 trees. The risk 4 trees failed to show the improvement in growth that the risk 1 trees have shown since 1936.

16. Twig growth is influenced by the weather of the preceding season while ring growth is influenced by weather of the current season. This is explained by the fact that shoot growth is formed from reserve food while ring growth is formed from currently produced food.

17. During the season of 1941, shoot growth was completed by July 7. Most of the needle growth took place from June 23 to August 25.

18. No insects or insect injury was noted on the analyzed trees which was materially contributing to decadence. (The role of Matsucoccus and Melanophila californica was not included as part of the present study.)

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